Accelerators for America's Future

ACCELERATORS
-
MODERN SHIPS OF DISCOVERY

October 26, 2009

MODERN SHIPS OF DISCOVERY

- THEY (*accelerators and the detectors that go with them)* TAKE US WHERE WE CANNOT GO UNAIDED

- ENABLE US TO SEE WHAT WE CANNOT SEE UNAIDED

- OUR STORY WILL

- tell of ships and adventures we've had (*tiny fraction*)
- ships and adventures that are soon to be launched
- ideas about possible ships for the future and what it takes to make them happen

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We'll be seeing about frontiers in

- Nuclear science
- Elementary particle science
- X-ray science
- Neutron science
- Science of Accelerators themselves

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- The Age of Accelerators began in the 1930's – well within living memory today – i.e. *modern*

- The very first startling result was realization of the Alchemists dream – changing one element into another (not lead into gold, however)

- in this case

$$(300\ \text{keV})p + Li \rightarrow Be^*$$

{ 300 keV ~ "3 billion °C" }

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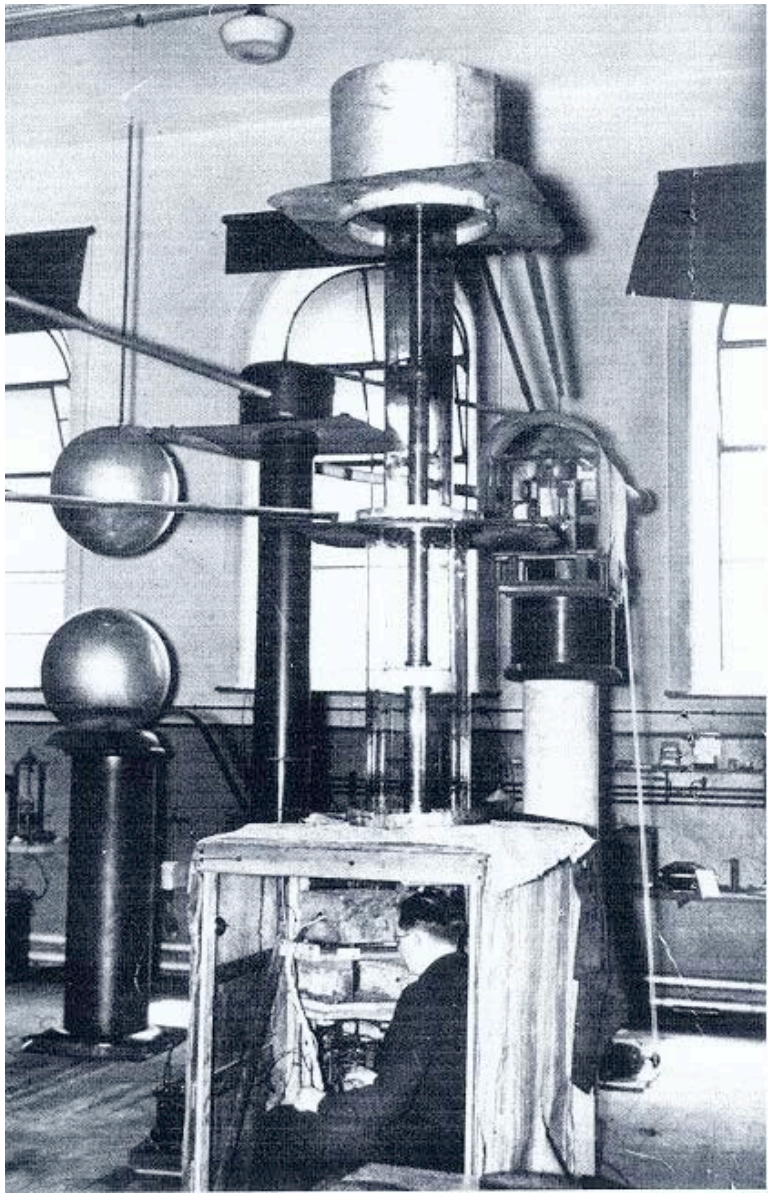

"Cockroft-Walton Machine"
(Rutherford's lab in Cambridge)

(300 keV) $p + Li \rightarrow Be^*$

Intensive and Extensive accelerator R&D between then and now has made spectacular strides

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Other amazing accelerator enabled results in Nulear Science

- Creation of more than 25 new chemical elements beginning with element 93, Np
- Measurements leading to understanding of power source of the sun and other stars
- Discovery that neutrons and protons change their character when inside nuclei
- Discovery of the "strong quark gluon plasma" – a state that may have existed early in the universe

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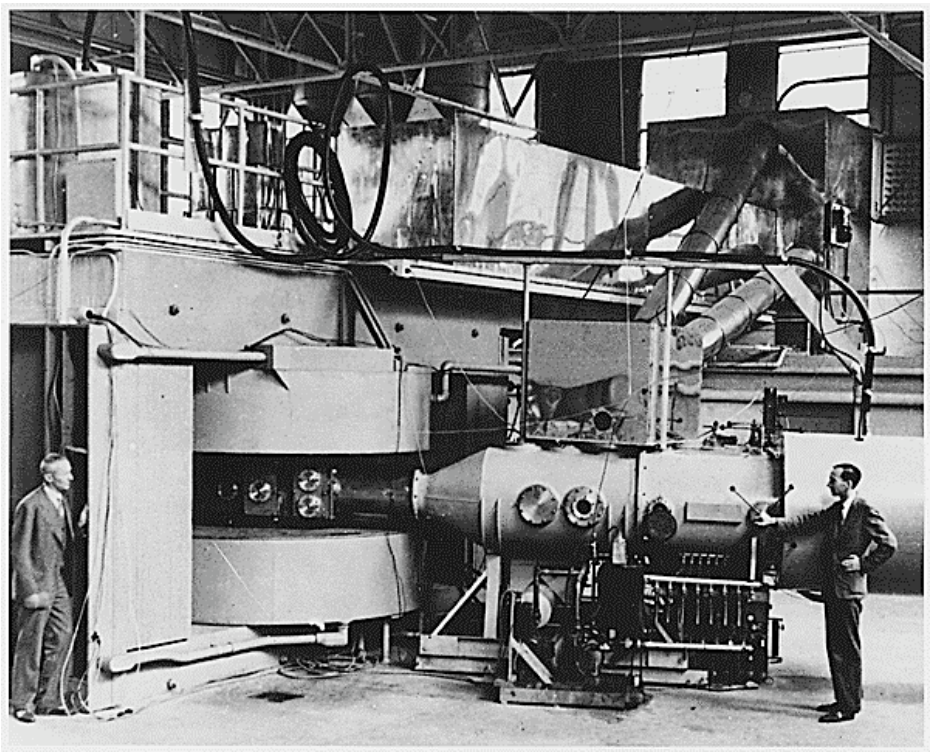
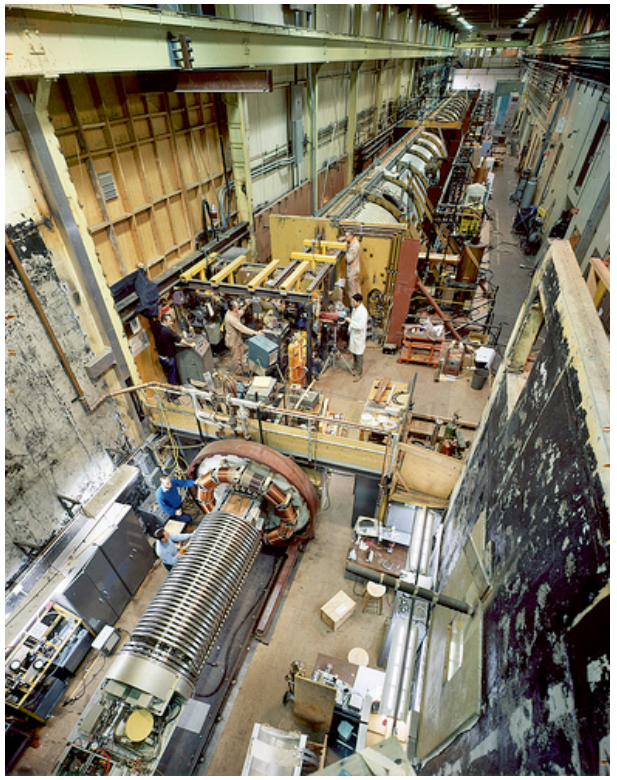
A very small sample of the machines that took us there



60 inch cyclotron



Super Hilac

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Collides heavy nuclei e.g. Au

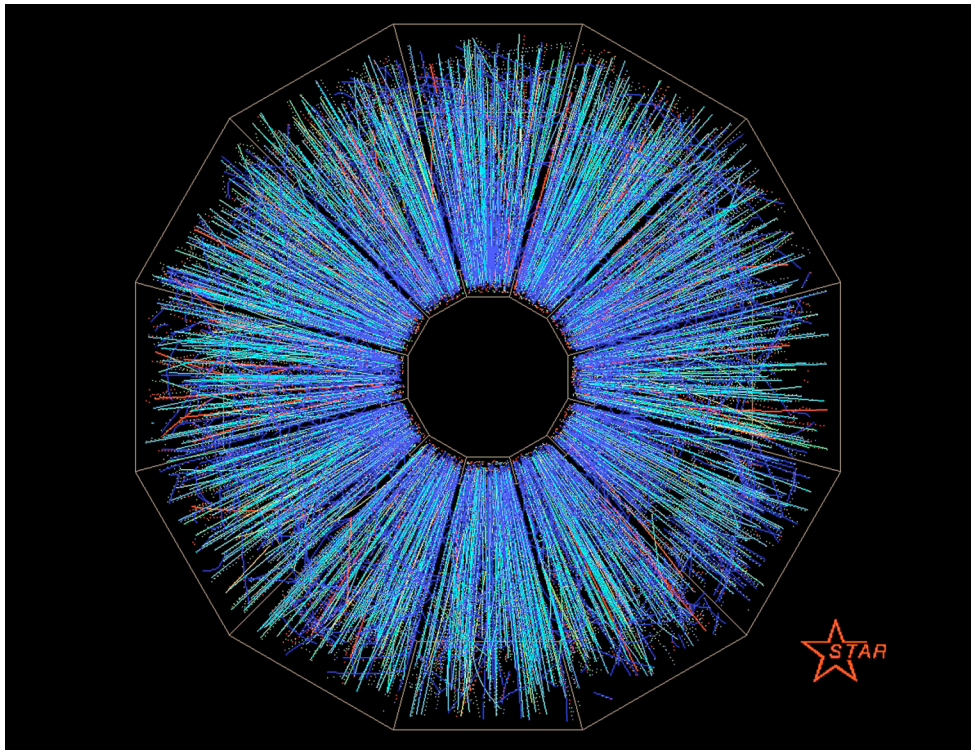
3.8 km circumference

0.1 TeV/nucleon

~20 TeV on 20 TeV (10^{12})

for Gold

RHIC



Picture of Gold nuclei colliding showing "strong quark-gluon plasma" *a state that may have existed shortly after the "big bang"*

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To

a very few of the amazing discoveries

in

Elementary Particle Science

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Discovery of:

- anti-proton showing matter-antimatter symmetry
- partons in protons by electron scattering
- J/psi meson
- two different neutrinos
- top quark

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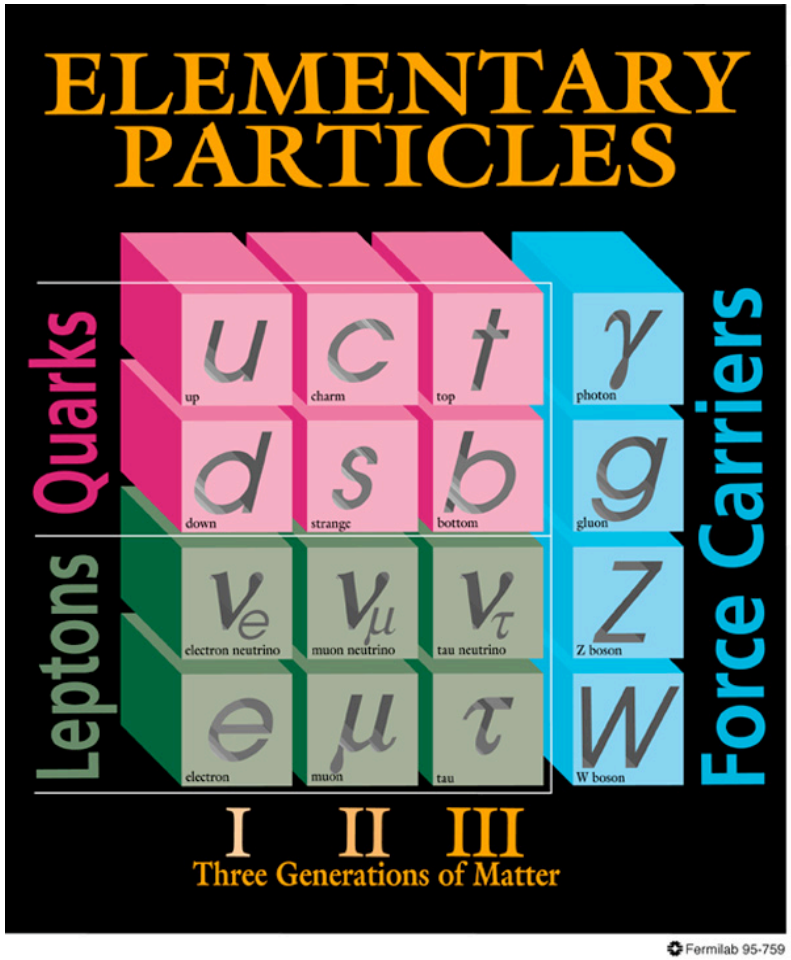
These and many other measurements and discoveries established the "Standard Model" of the visible world



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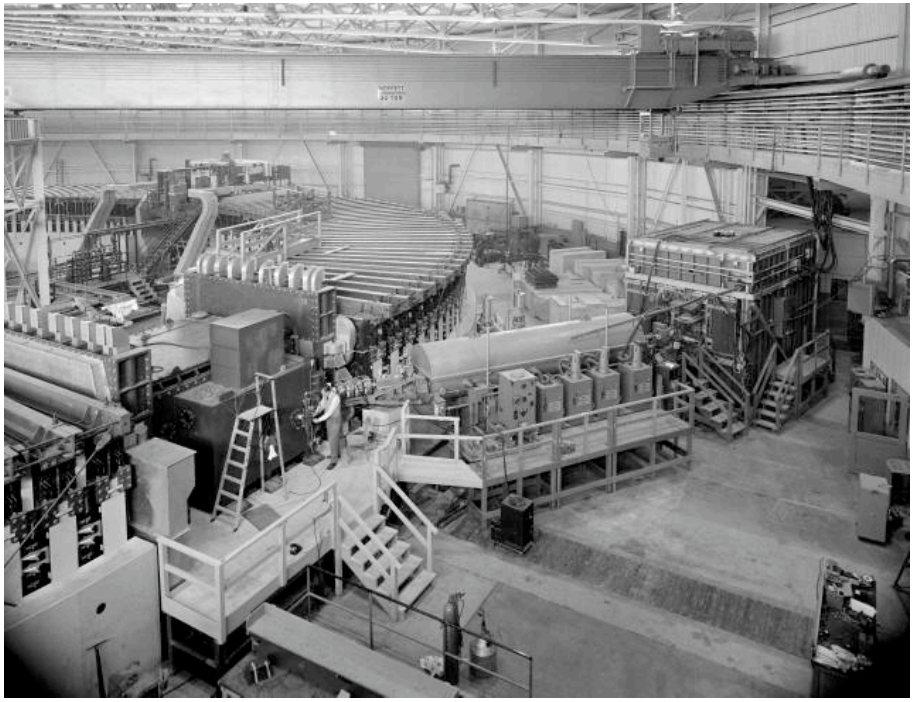
A very small sample of the machines that took us there



Bevatron 6.2 GeV (10^9 eV)

SLAC linac 3 km 50 GeV

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Tevatron 6 km circumference
1 TeV on 1 TeV collider
(10^{12} eV)

AGS 30 GeV 1km around

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To

some outstanding results in

X-ray based Science

using *synchrotron radiation* from accelerators

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- Structure of rhinovirus –lead way to 3D of others
- Potassium channel in cell wall for nerve transmission
- Diamond anvil cell high pressure mineral phases
- Real time imaging of, e.g. insect breathing
- Magnetic scattering
- Structure of the ribosome

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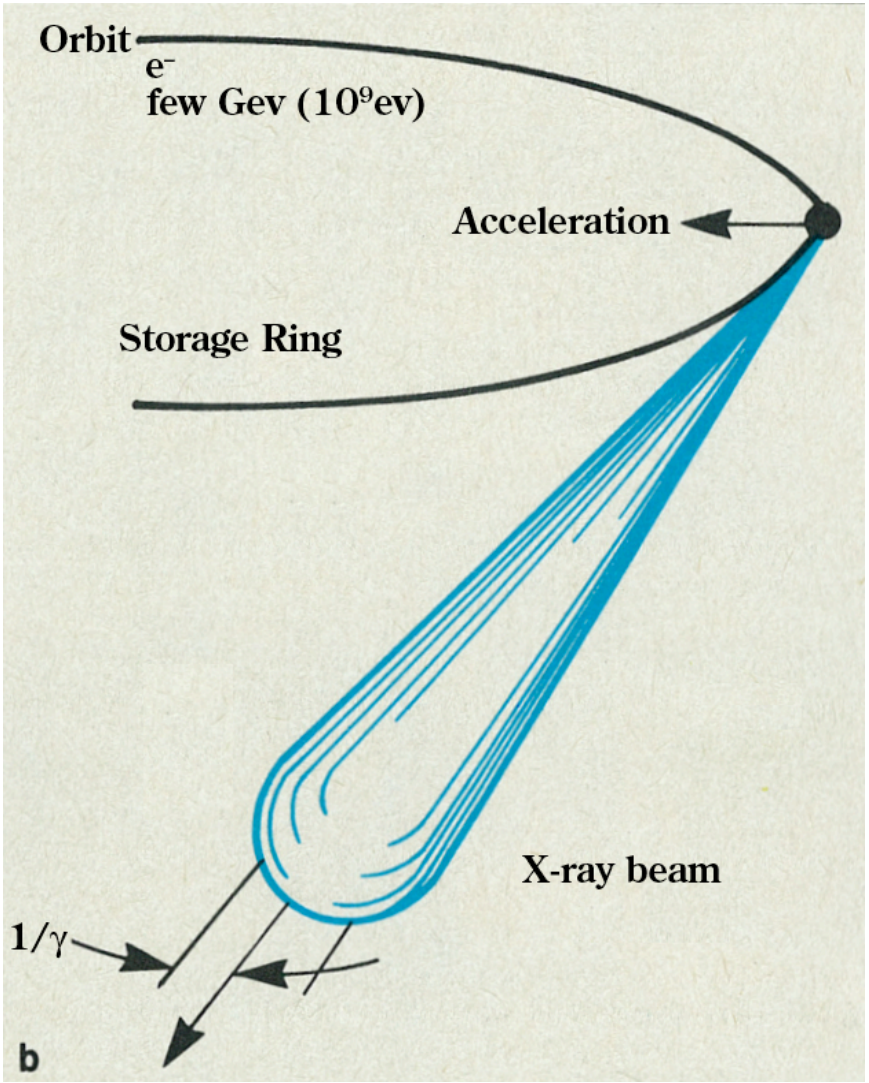

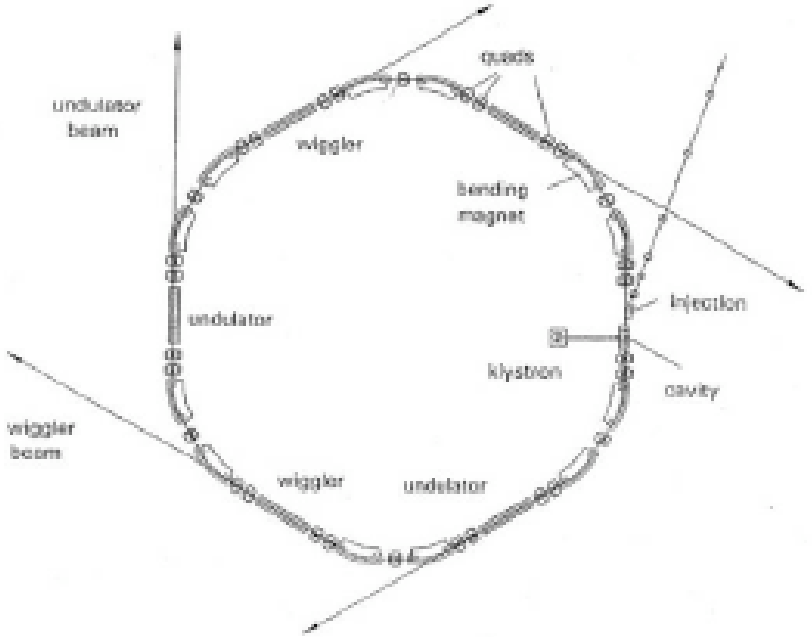

Storage Ring

10's of users of the SR can work simultaneously

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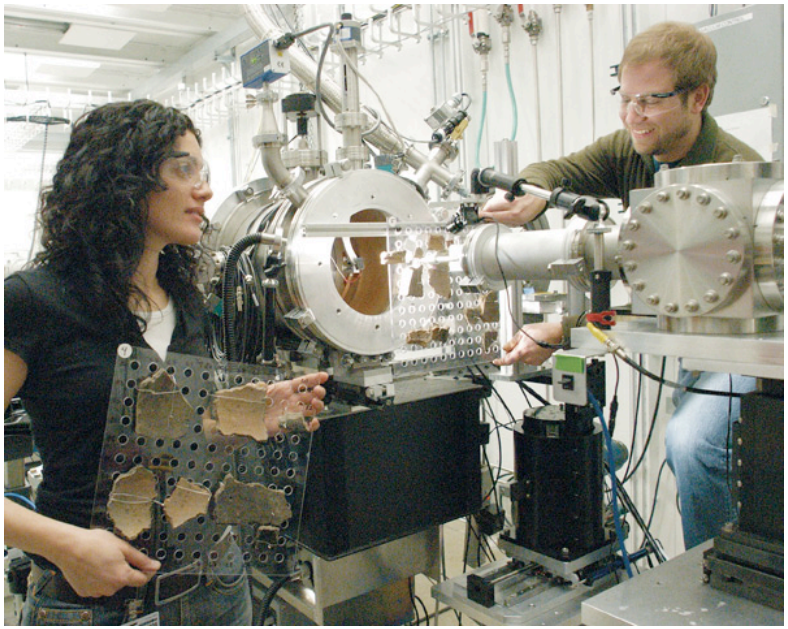
Facilities that house storage rings for hard X-rays

7 GeV, 1.1 km circumference



at a beamline

The Advanced Photon Source, one of six "hard" X-ray sources in the US

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to some outstanding results in

Neutron Assisted Science

based on accelerator produced neutrons

(several results reported from work abroad)

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- magnetic resonance in iron pnictide associated with Hi Tc superconductivity
- structure details of "colossal magneto resistance" materials
- change in structure of water with pressure near freezing
- structure of important ionic liquids
- 2 phases of C60 (*BES logo*)

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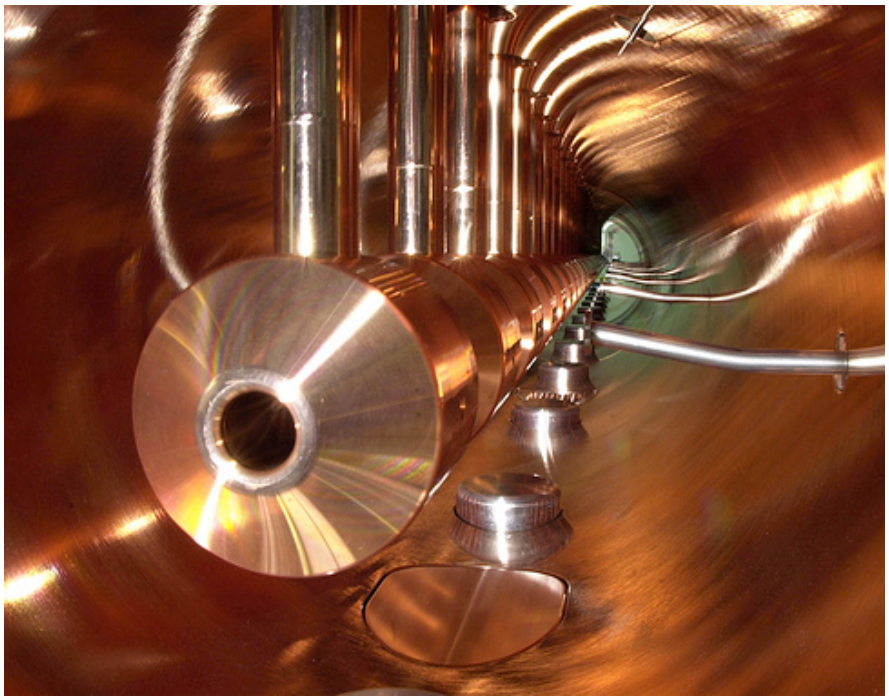
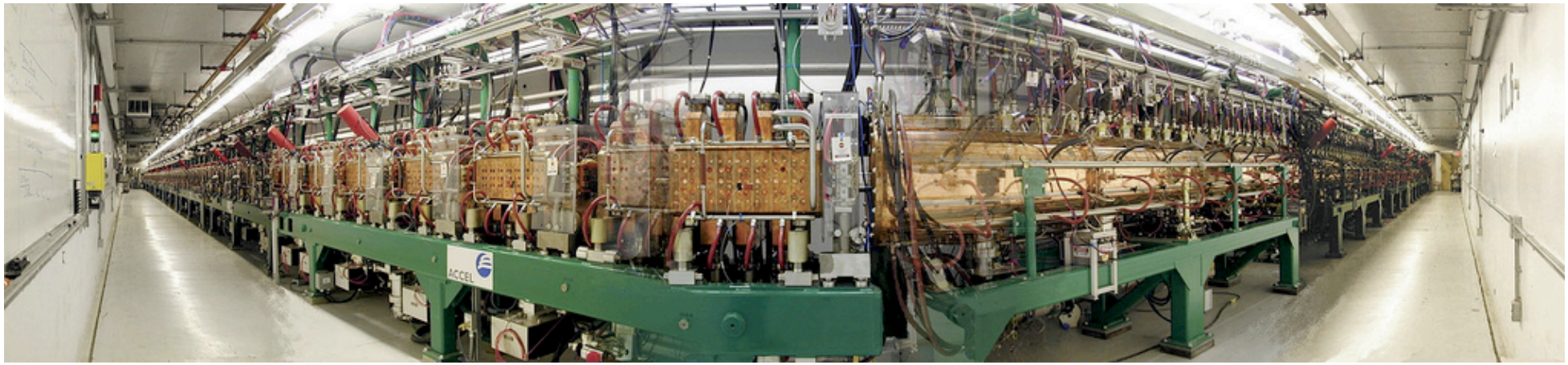
US Accelerator based neutrons

inside S N S





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to

THE SCIENCE OF ACCELERATORS THEMSELVES

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- in addition to the many accomplishments exemplified by the accelerators we've just seen examples of
- in addition to the many developments of the underlying science and technology on which those accelerators are founded
- there are recent advances of special note which exploit the plasma medium in which separation of charges can support enormous electromagnetic fields
- two approaches are being developed: producing the separation with particle beams or with lasers

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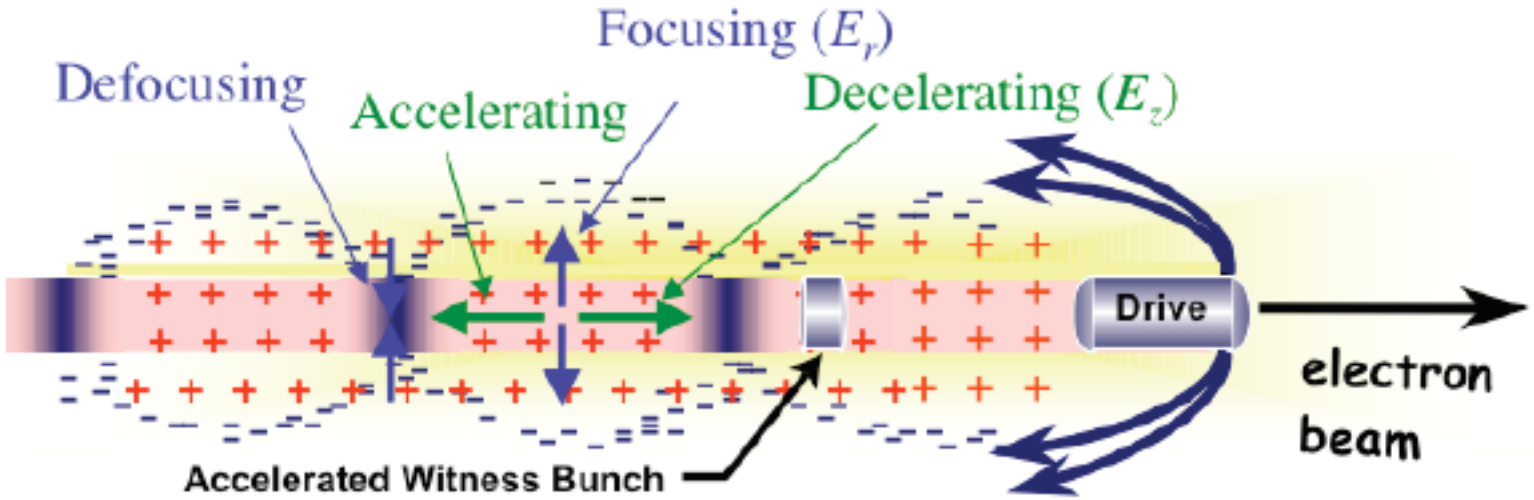
Beam driven plasma acceleration



the "drive" electron beam deposits energy in the plasma in the form of a charge separation which accelerates the "witness" beam of electrons to a high energy

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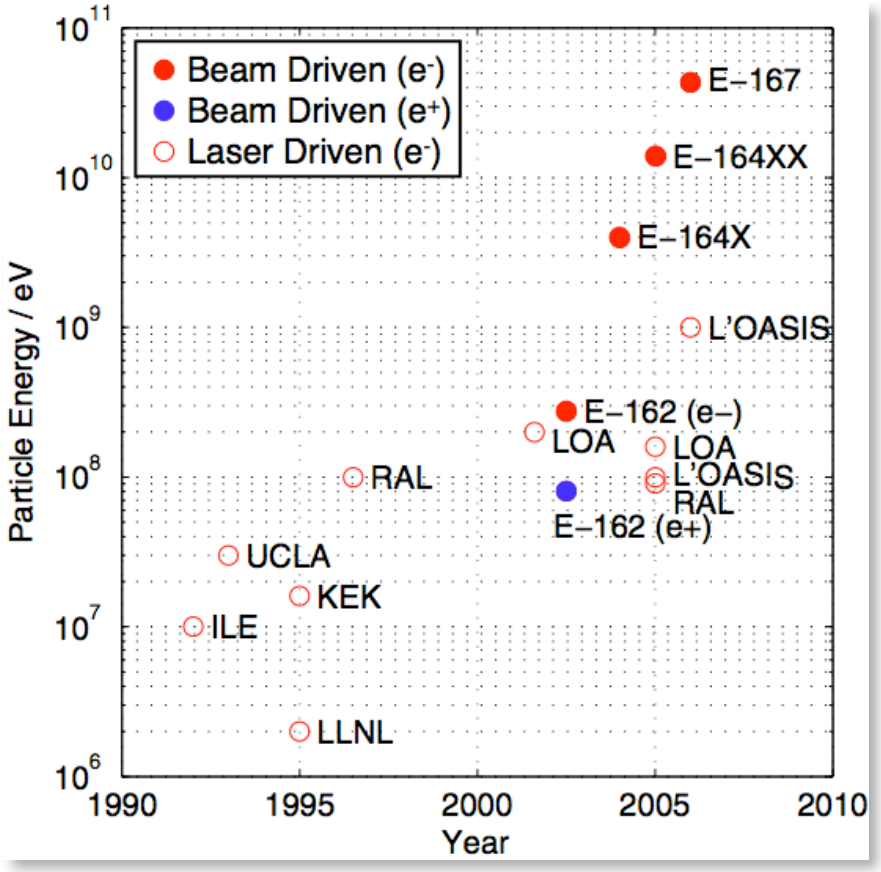
Beam driven plasma acceleration results



- Measured Accelerating Gradients of ~50 GeV/m (3,000 x SLAC)
- Many aspects of beam-plasma interaction have been studeid:
- Focusing & transport
- Radiation production
- Refraction/Boundary effects
- Acceleration of e^- and e^+

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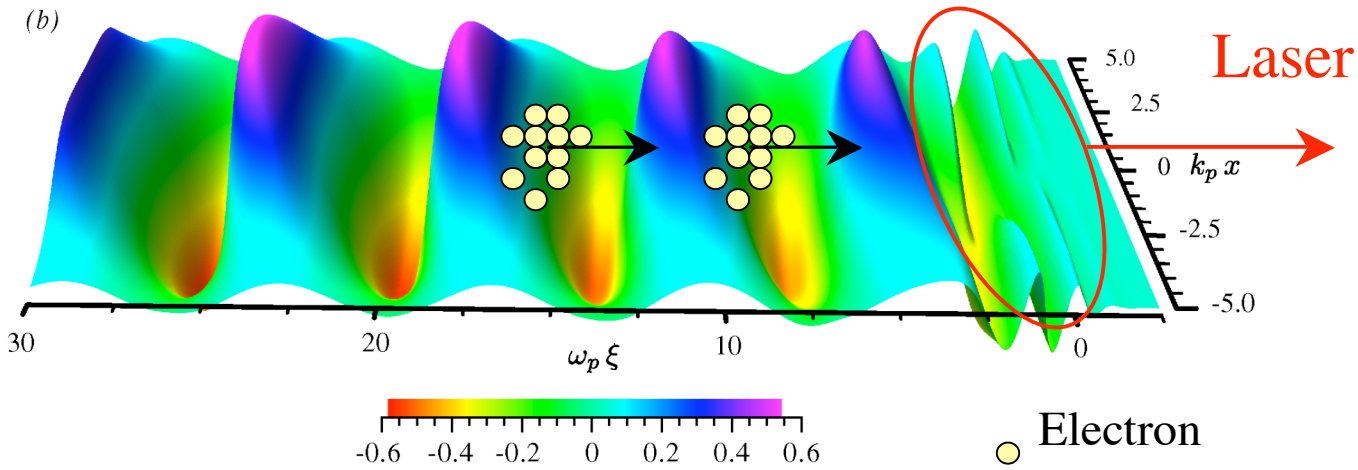
Laser driven plasma acceleration



The laser pulse organizes the plasma, producing the charge separation that produces the accelerating field

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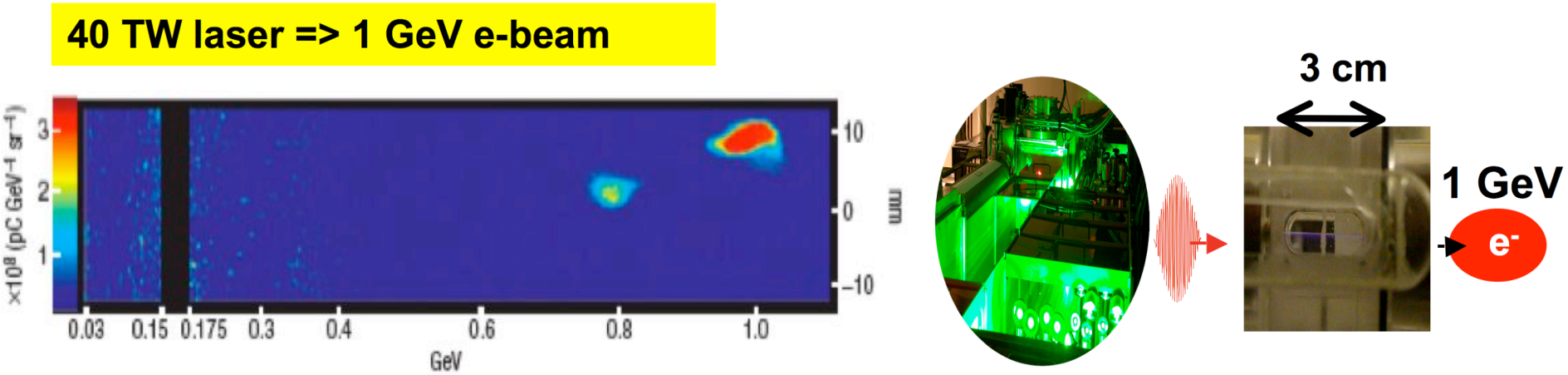
Laser driven plasma acceleration results

40 TW laser => 1 GeV e-beam



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That's our sampler of a small bit of accelerators and accelerator based science bringing us up to date

Now let's see about commitments coming up soon:

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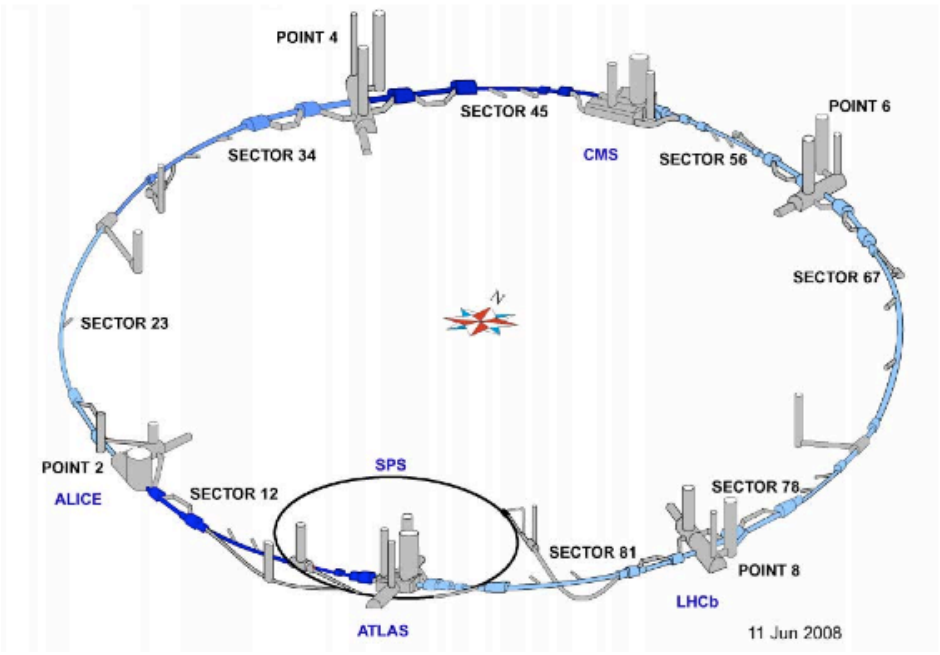
The energy frontier is moving abroad

LHC – Geneva Switzerland

Artist's Cutaway



27 km circumference

7 TeV on 7 TeV

begin data this year

Will be used for discovery

elementary particle physics

and heavy ion physics (NP)

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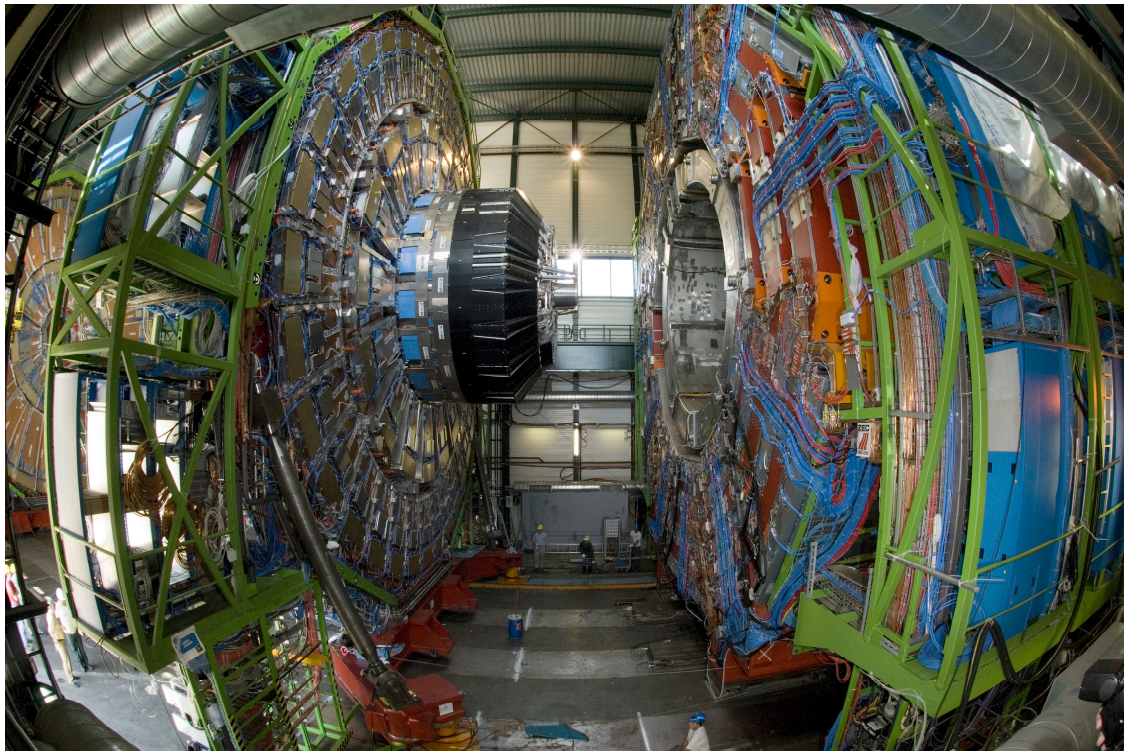
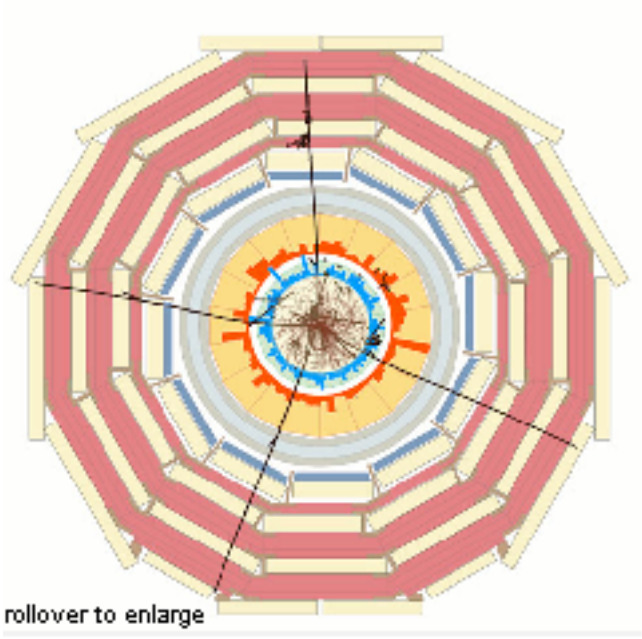
CMS Detector





Notice persons at bottom for scale

Simulated Higgs decay

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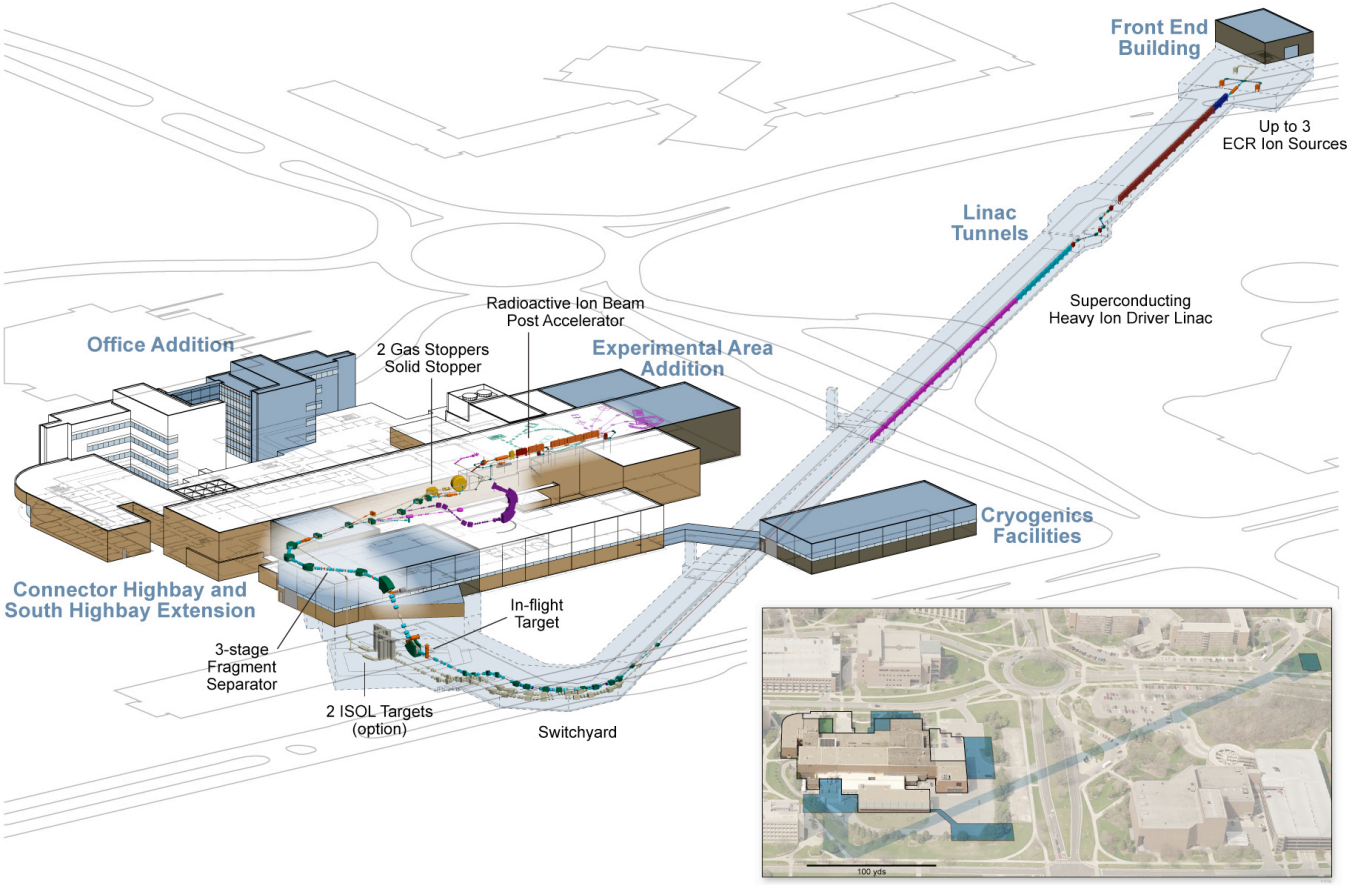
Now under way for Nuclear Science US : FRIB



- Science of stellar interiors, super novae, x-ray bursts…
- Testing symmetries of nature and more

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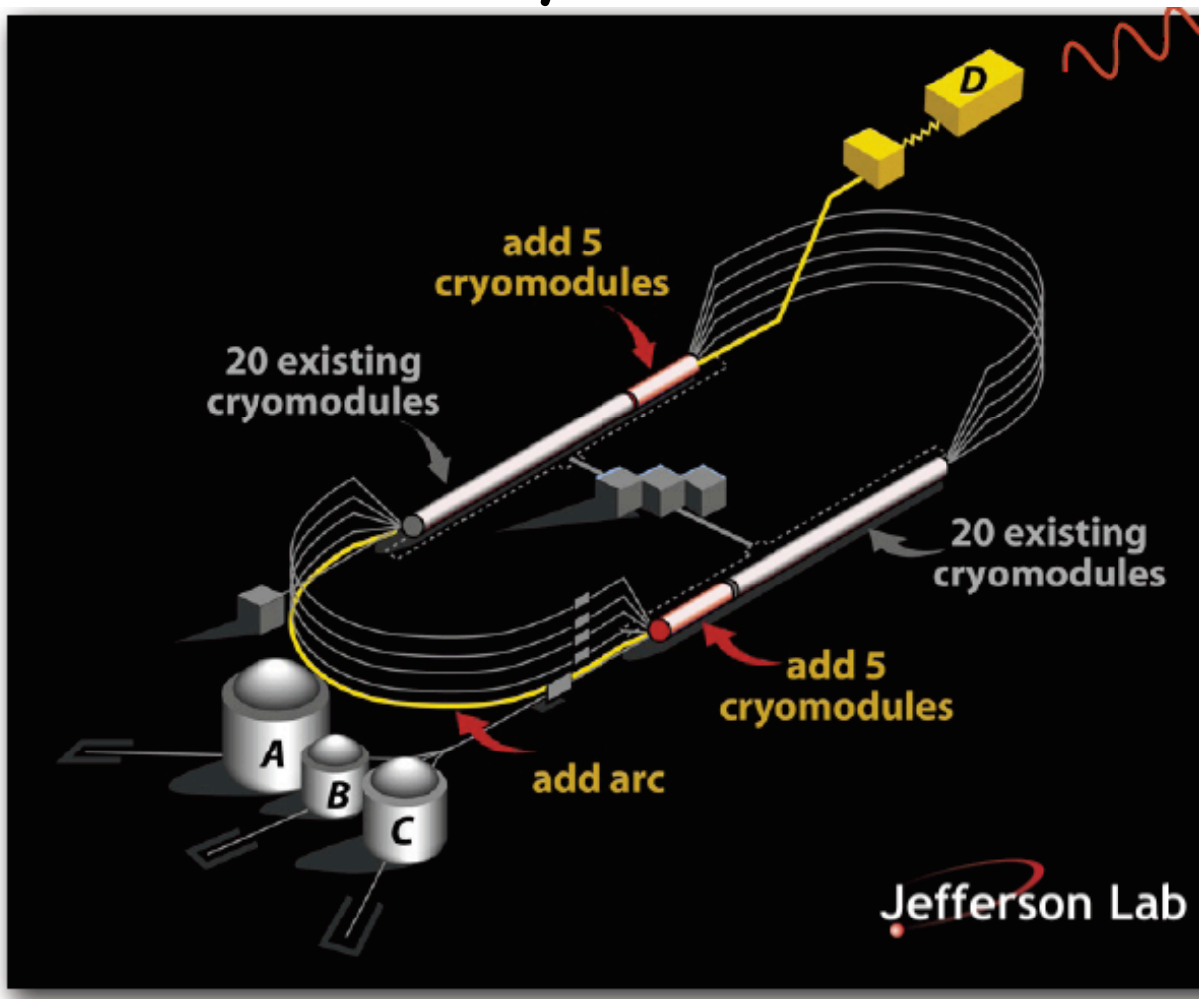
Now under way for nuclear science – CEBAF upgrade



Employs e and γ
To explore the properties of the nucleus.

Upgrade raises energy to 12 GeV

Ultimate goal – understand how confinement works

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And-

Here's a look at what's coming on in accelerator based

materials science

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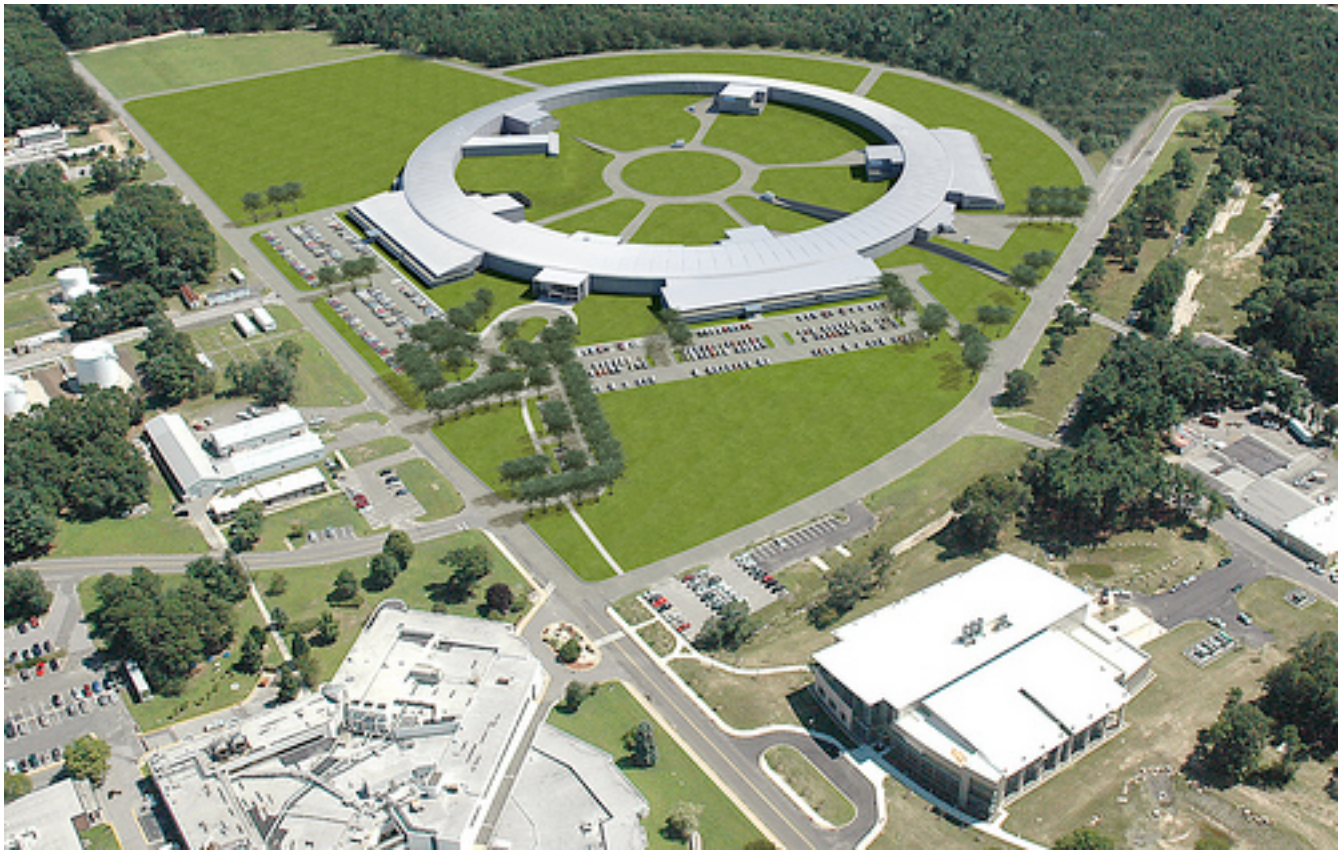
Now under construction



NSLS 2
Will offer a significant advance over existing US storage ring sources

3 GeV, 791 m circumference

The brightness improvement planned will allow imaging of nano particles with near atomic level resolution

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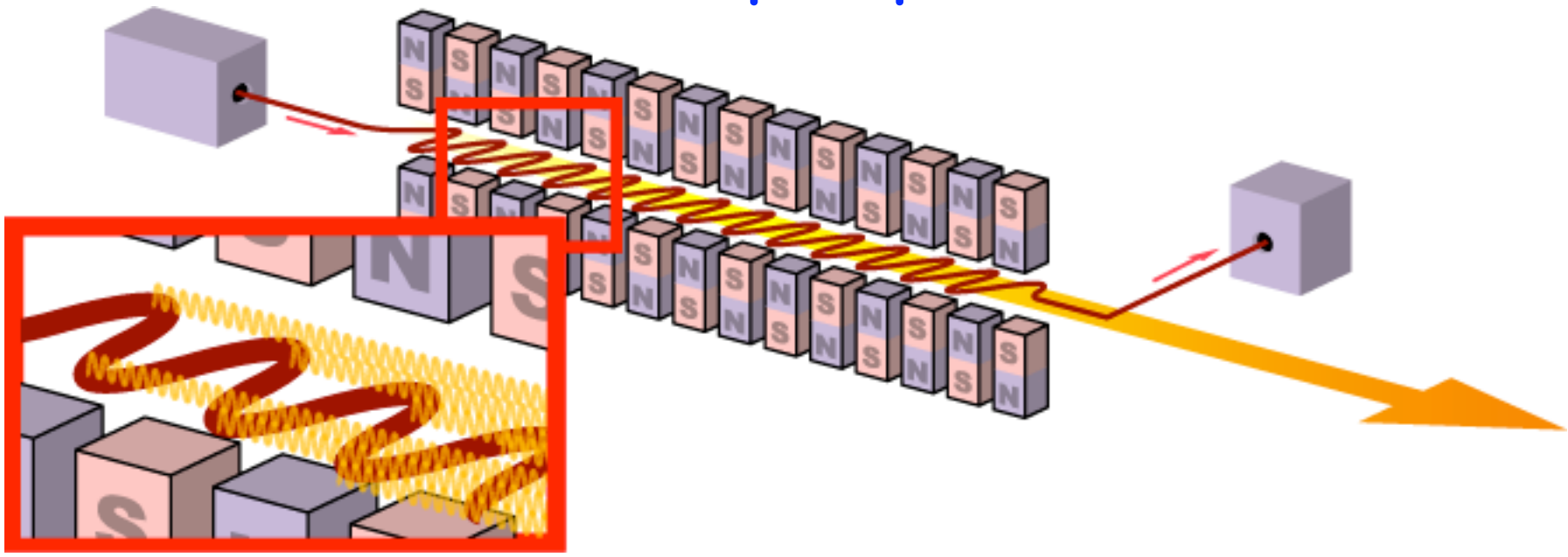
New on the scene here is the Free Electron Laser able to produce "hard" X-rays with wavelength comparable to atomic dimensions with unprecedented brightness and pulse lengths in the femtosecond (10^{-15}s) range.

Enables atomic level measurements of ultrafast events

The principle:



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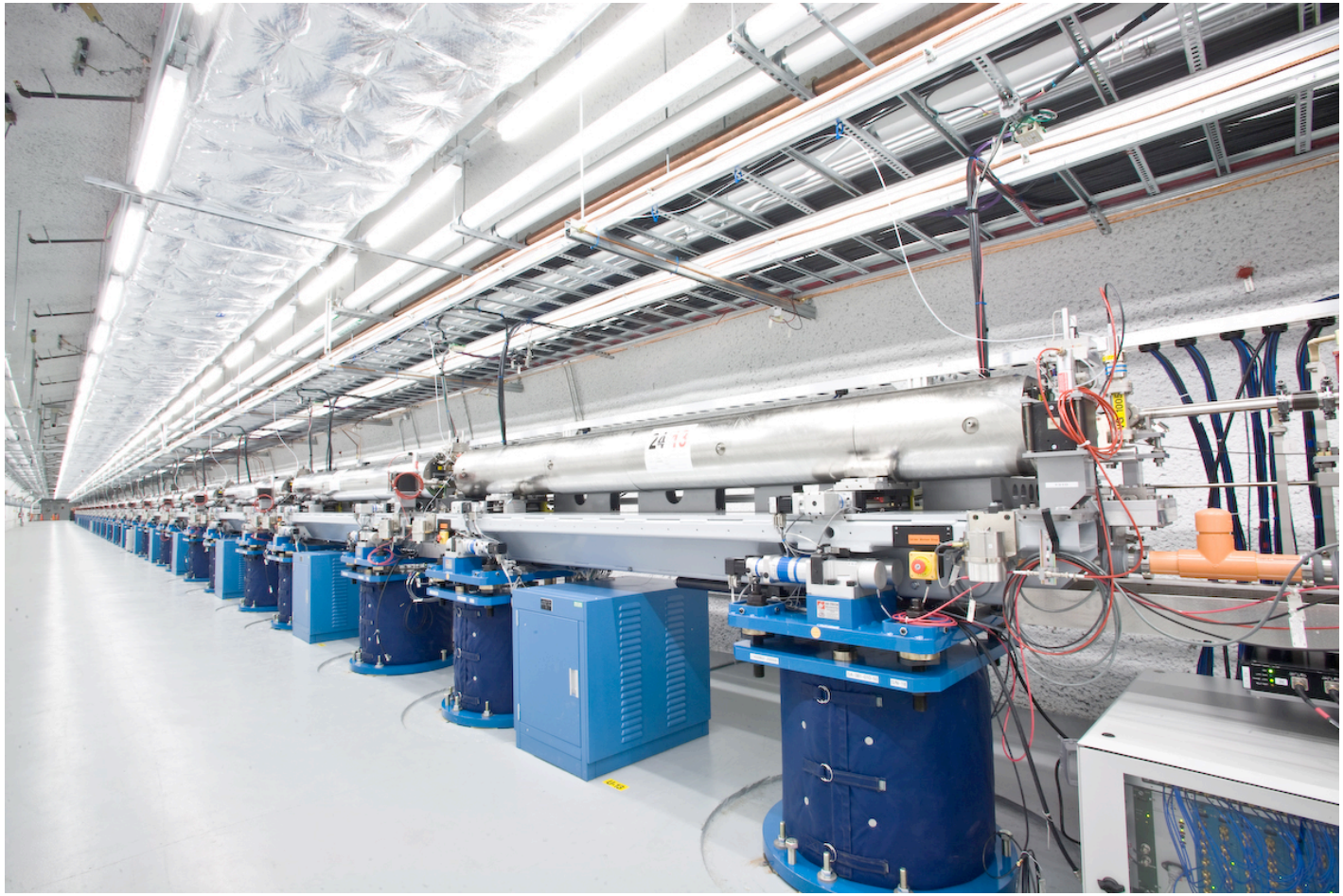
LCLS conversion of SLAC linac



SLAC Science program just getting under way now

Stands to permit determination of structure of important life molecules with a single molecule rather than in crystalline form and much more

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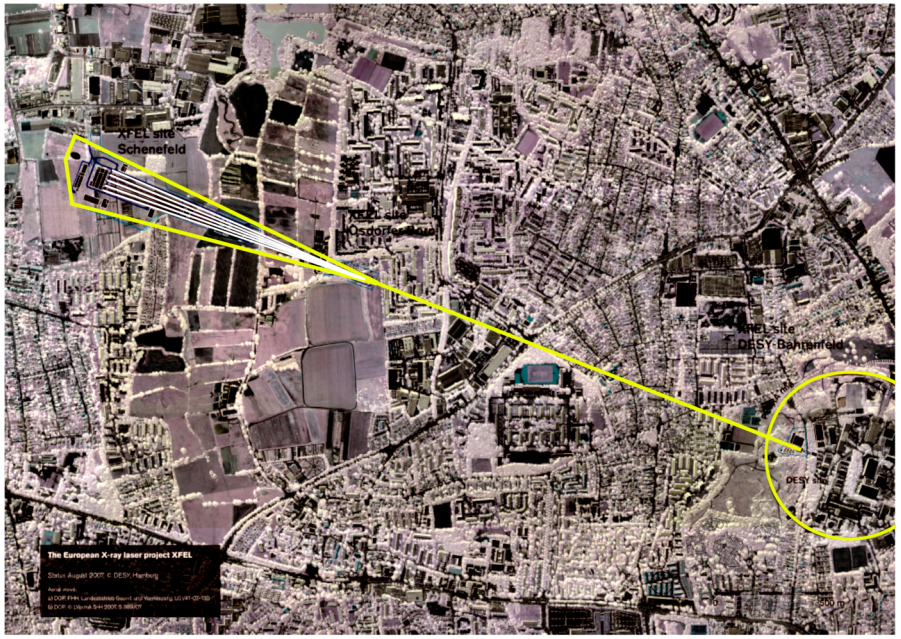
European XFEL



A "purpose built" hard X-ray FEL (0.1 nm wave length)
using superconducting radiofrequency technology
- highest average spectral brilliance -

now under construction

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And

Two new test facilities

for the Science of Accelerators

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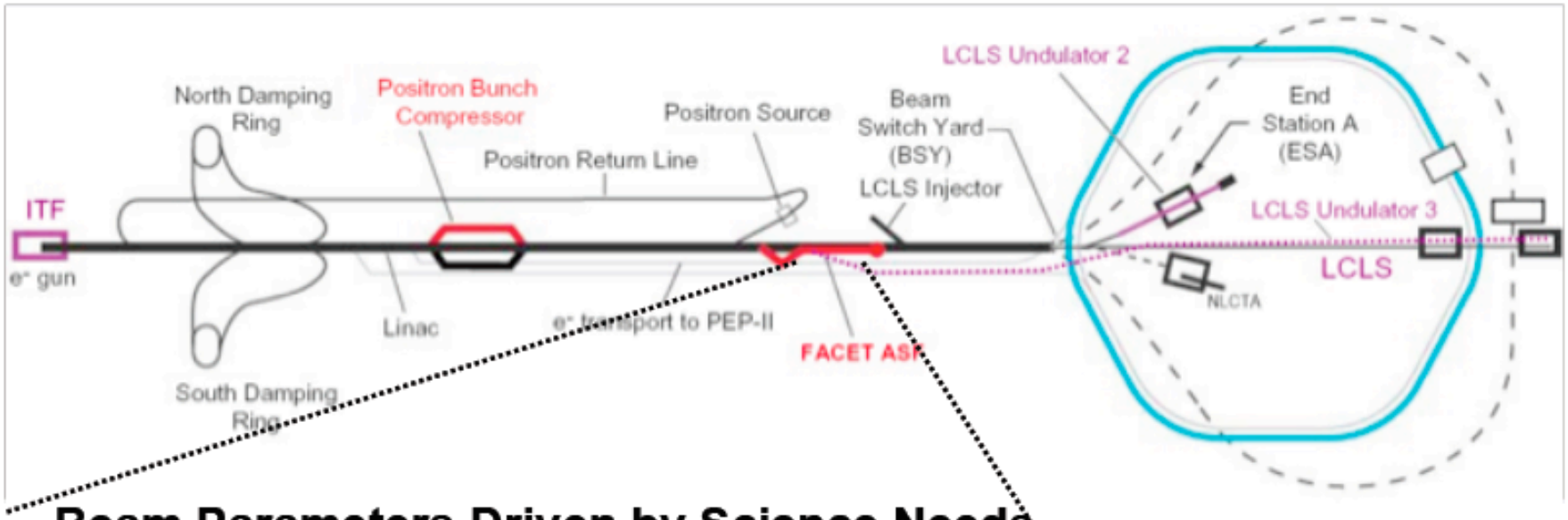
FACET - facility



Beam Parameters Driven by Science Needs

Delivered to 100m area with three distinct functions:

1. Chicane for final stage of bunch compression
2. Final Focus for small spots at the IP
3. Experimental Area

Advantageous location:

- Preserves e+ capability
- No bypass lines or interference with LCLS
- Linac setup virtually identical to SPPS/FFTB

FACET

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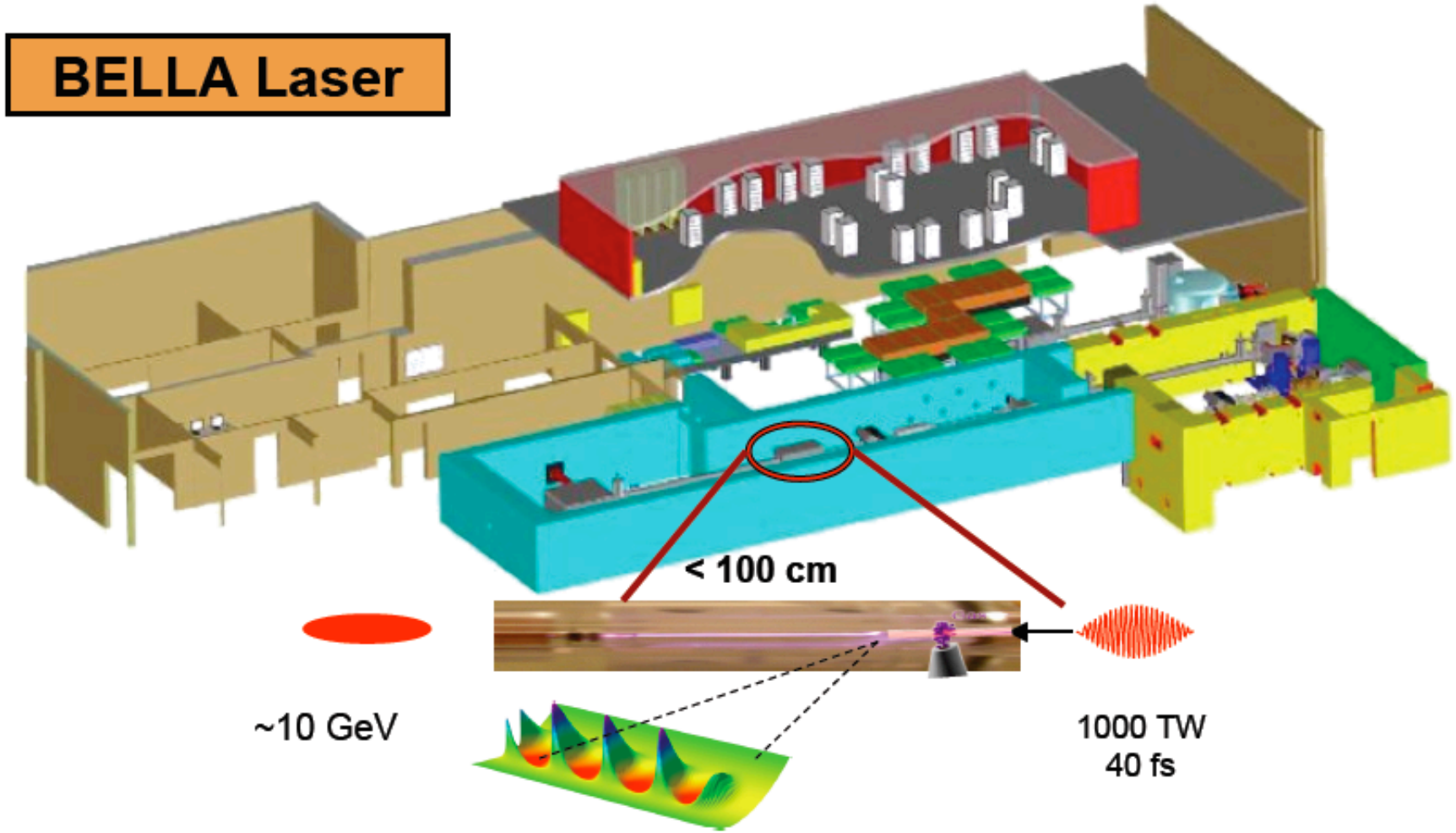
Laser Driven Plasma Acceleration – BELLA – facility LBNL



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LOOKING NOW TO THE FARTHER FUTURE AND A FEW OF THE ACCELERATOR POSSIBILITIES THAT ARE UNDER ACTIVE DISCUSSION WITH SOME R&D

First Stop

X-ray Science

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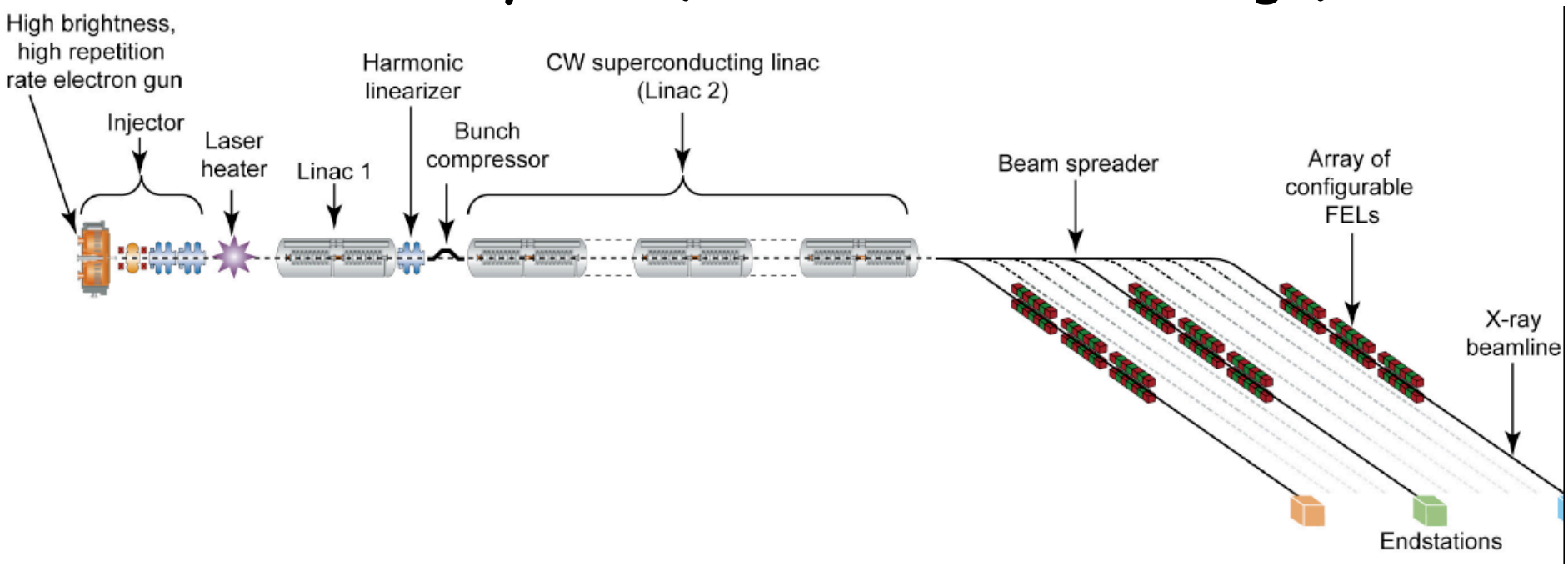
Soft X-ray FEL (down to 1 nm wavelengh)



At these longer wavelengths it may be possible to use "seeding" with an optical laser to gain control over the temporal as well as spatial nature of the soft X-rays, to see how atoms are bound together in solids, Hi-Tc….

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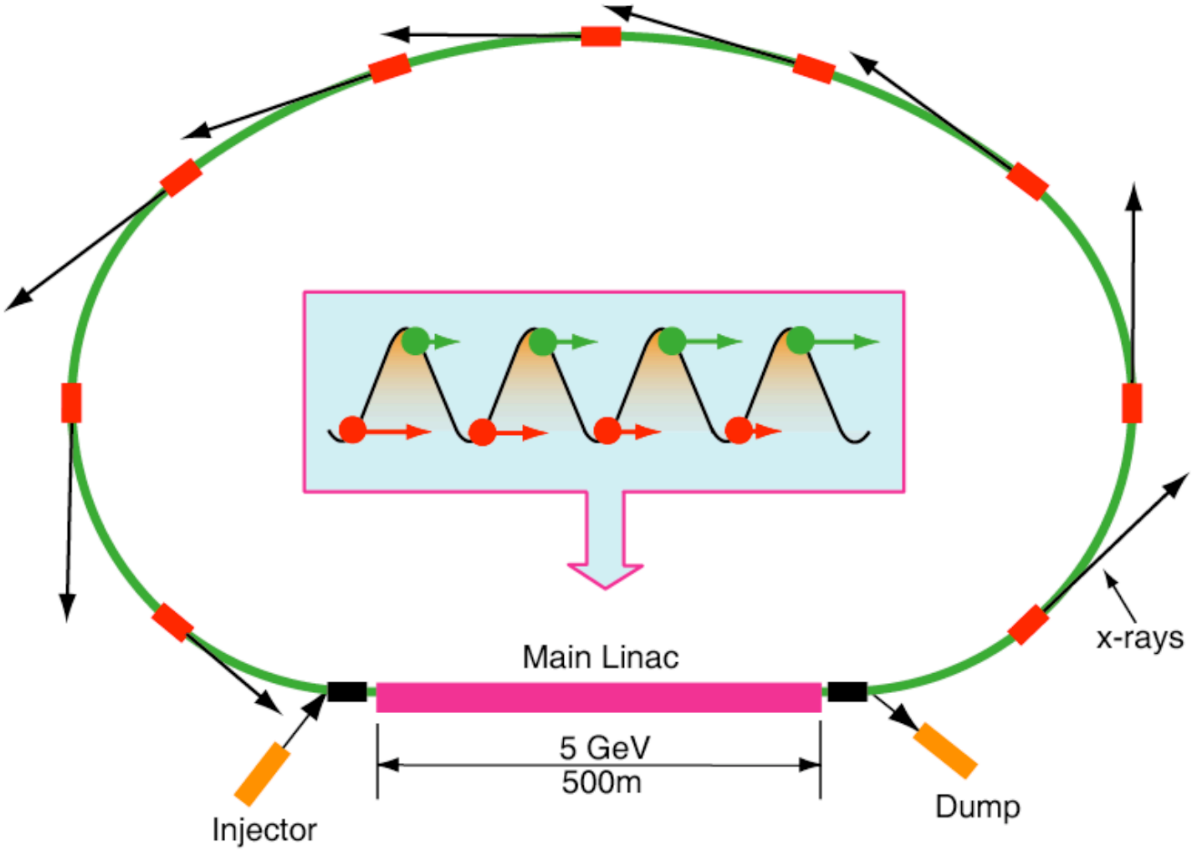
Energy Recovery Linac, ERL



Both hard and soft X-rays

X-hi brightness accesses smaller objects down to atom size

e.g. make movies of catalysts in action

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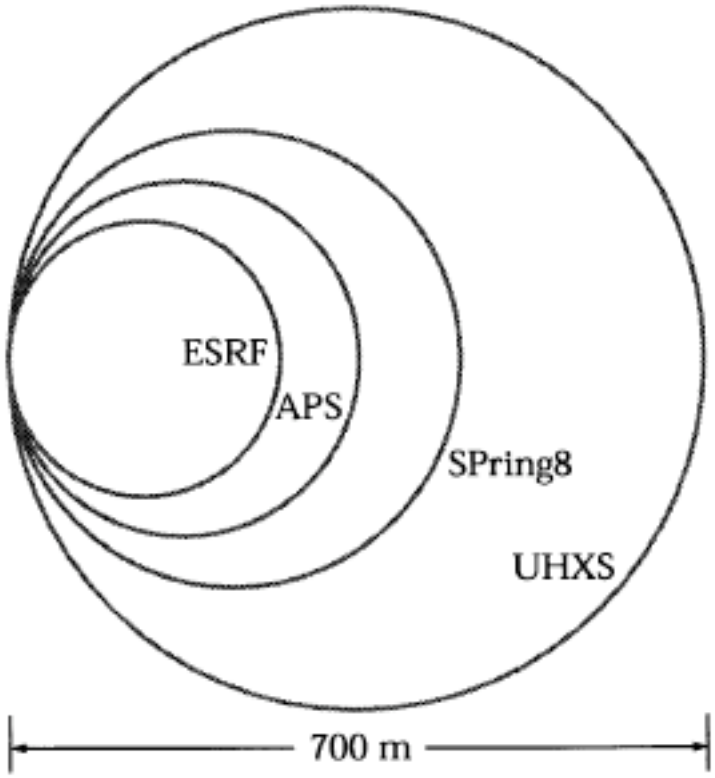
Ultimate Hard X-ray Storage Ring



It is thought that perhaps a large enough storage ring with special provisions might rival the X-ray brightness of linac based sources but without the short pulses

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Now on to possible advanced accelerators of the future for Nuclear Science

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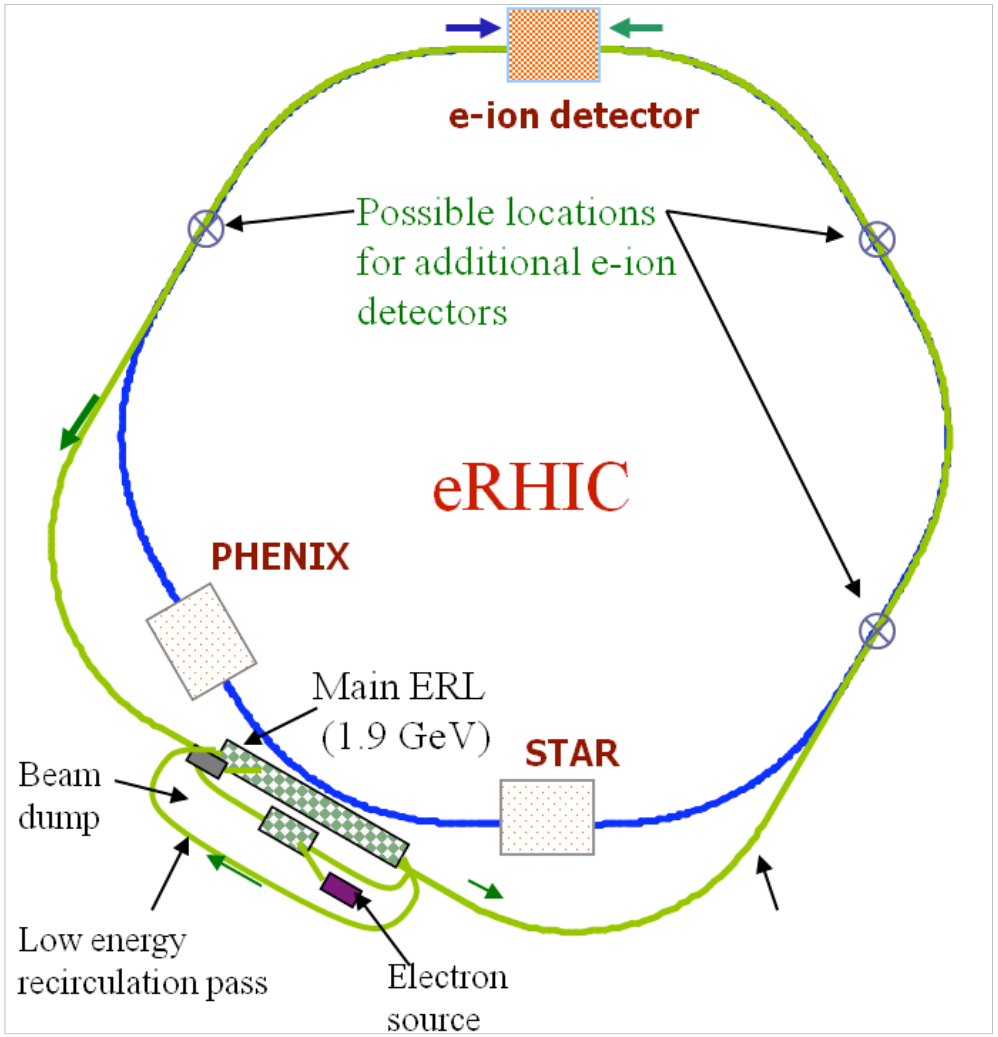
Electron-heavy ion collider eRHIC one possibility



Enables us to look in detail into the sea of quarks and gluons in nuclei, to create and study gluons with hope to discover how energy transforms into matter.

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And for High Energy Physics

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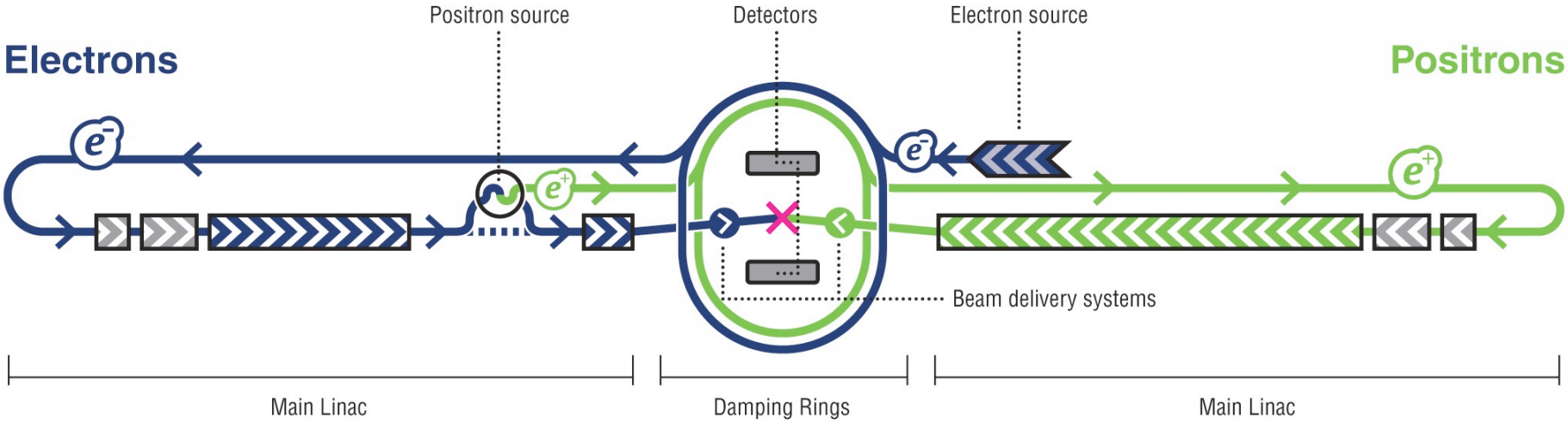
ILC International Linear Collider



0.5 – 1 TeV total, 33 km length

Identify dark matter suspects, enumerate extra dimensions, check whether Higgs particle suspect(s) fulfill all required characteristics…….

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or perhaps another approach

And for the yet further future – perhaps a muon collider,,,,,,,,,,,,,,,,,,,,

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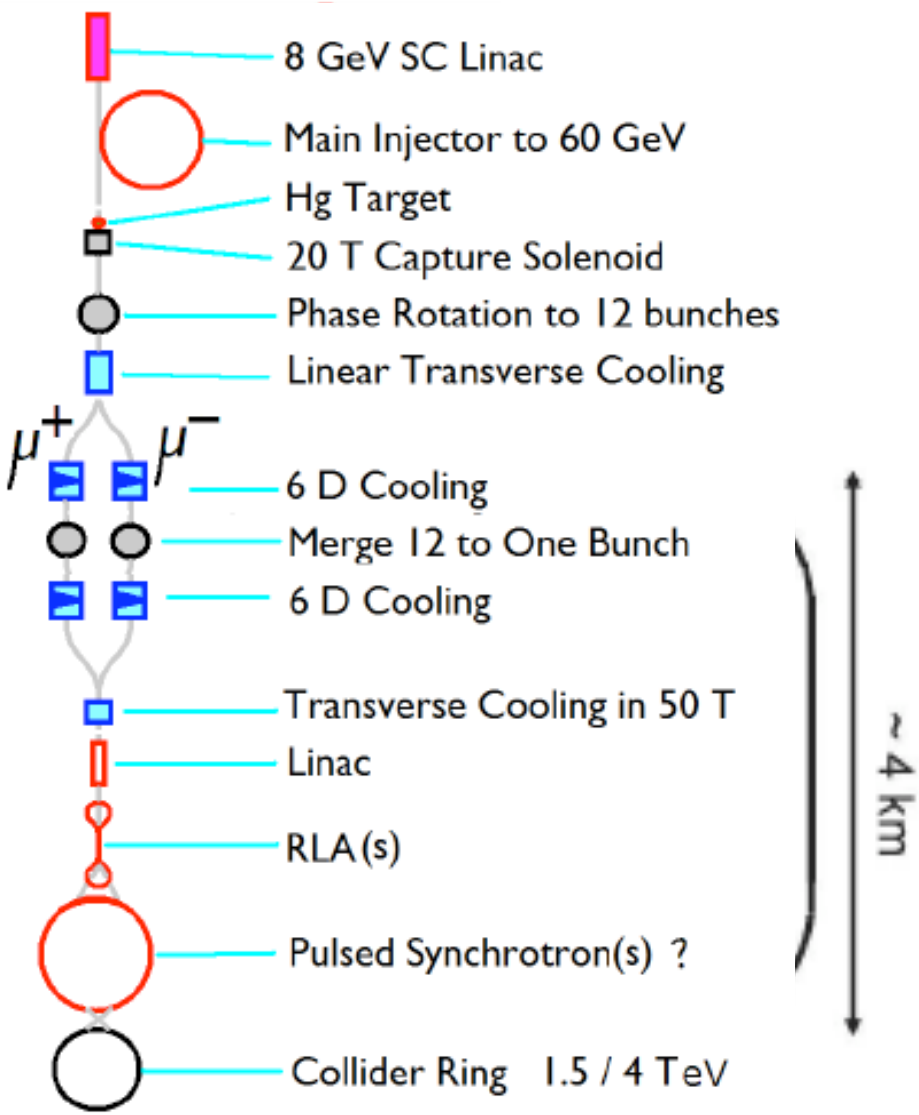

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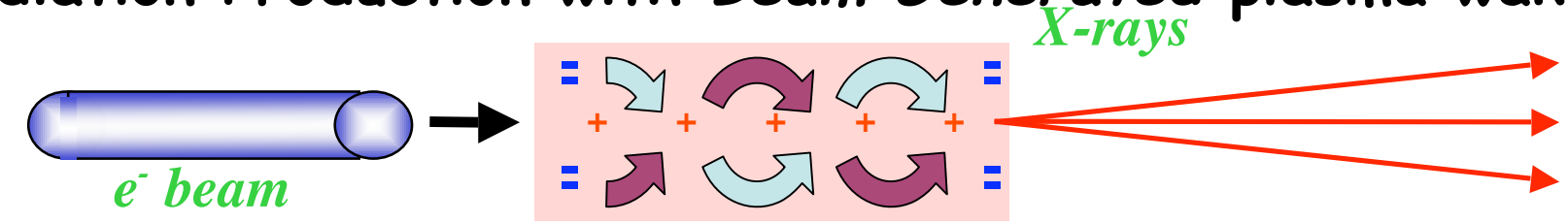
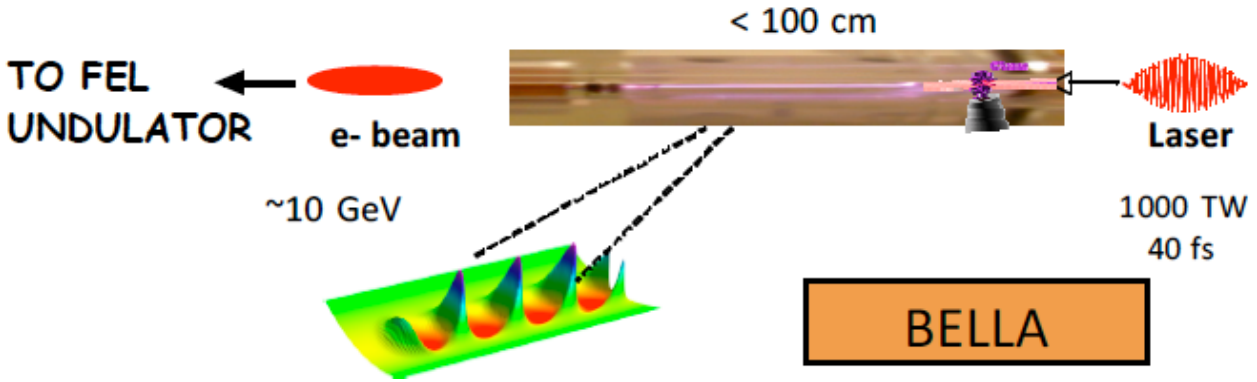
Future possibilities for Plasma based acceleration

Radiation Production with *Beam Generated* plasma wakefield



It may eventually be possible to apply these principles to obtain very high energies for elementary particle physics

Radiation production with *Laser Generated* plasma wakefield



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We've seen:
Small samplings of where we've been,

What we are committed to for the near and mid-term,

Where we might go in the further future in accelerators for the accelerator based sciences and in the *science of accelerators*

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Assuring future accelerators

to support the evolution of sciences depending on

accelerators requires a conscious and continuing effort

in support of the science of accelerators

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Accelerator science is a SCIENCE and needs to be conceived of as such in order to nurture it properly. As in other sciences it is built up step by step with syntheses and implementations often taking many years for acceptance of the ideas and development of the technologies needed for that implementation.

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The collage below displays some of the scientific and technology elements that have played and are playing important roles in bringing accelerator science forward and in realizing implementations now in late stages of development – generic accelerator R&D elements.

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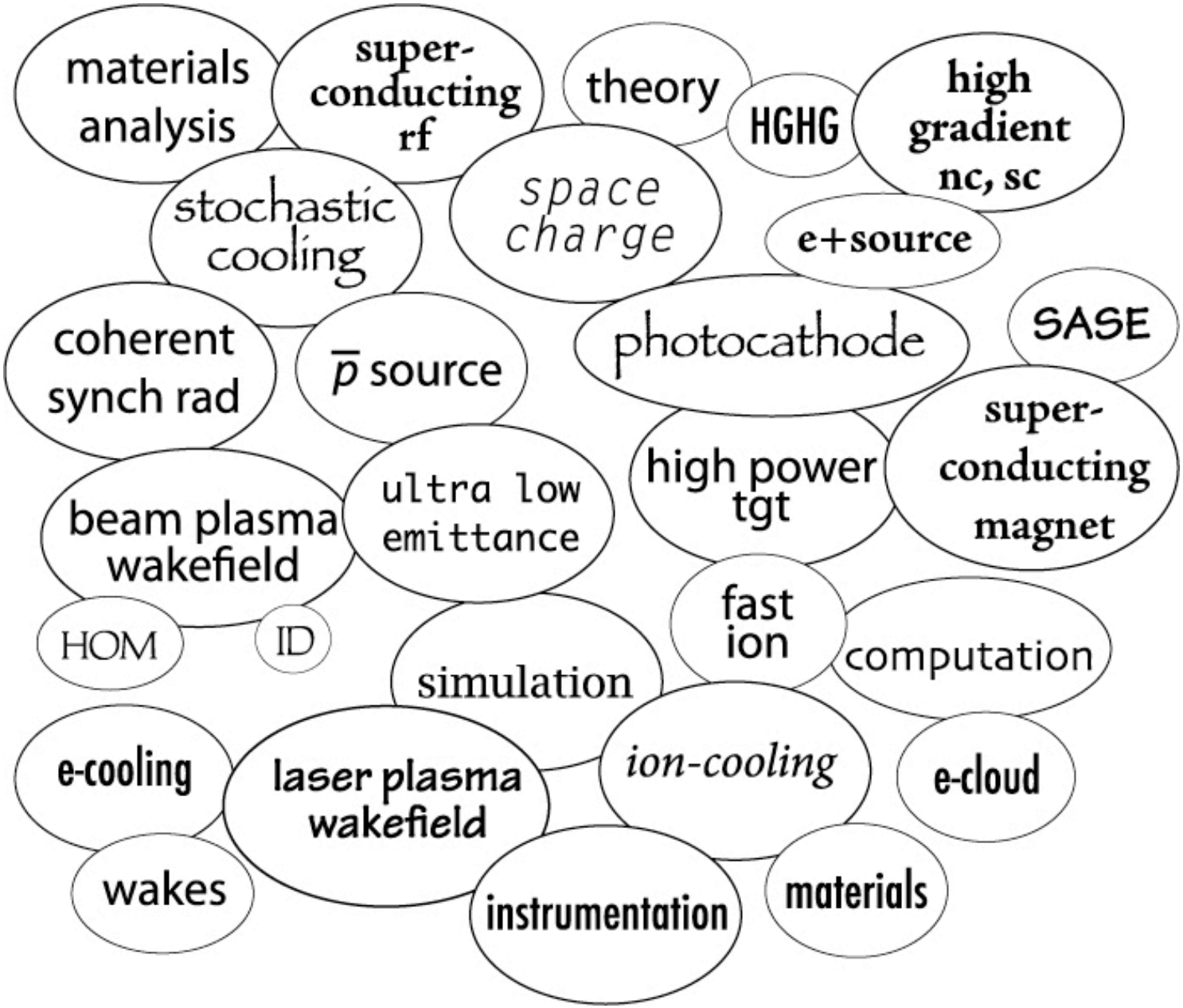

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STRONG SUPPORT FOR THESE ELEMENTS IS ESSENTIAL FOR ASSURING

Accelerators for America's Future

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ACKNOWLEDGEMENTS

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P. Oddone

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